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Experimental Cost Reduction in Pump Manufacturing Industries through Software based Mechatronics System

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Abstract

Nowadays, the changing demand patters by the customers are increasing the pressure on the manufacturers. In this situation, manufacturers are forced to do (i) increase the selling price of their products and (ii) reduce the internal costs of their organization. In this scenario, because of buyers market, it is not possible to increase the selling price of the products. The only way is to reduce their internal costs and improve the performance of their organization to survive in their field. This paper suggests them to implement the software based mechatronics systems in their premises in order to reduce the experimental cost, experimental lead time reduction, improve data accuracy, data reliability and improve their performance. The software based mechatronics approach is used to construct the virtual machinery instead of physical machinery for the experimentations. The usefulness of this approach is not only applicable for pump manufacturing industries but also various industrial segments, which would enable to cater the current and future customer demanding needs.

Key words: Virtual machinery, software based mechatronics system, LabVIEW software, heat generation, experimental cost reduction, internal cost reduction

1. Introduction

As global competition continues to intensify across industries, companies are actively pursuing strategies that will enable them to compete more effectively and efficiently. Dantar (2010) [1] expressed that over the past decade the application of the innovative principles has emerged as the primary improvement strategy in companies around the world. As claimed by Karen and Mike (2007) [2],

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together the different variations of the new approach have emerged as the predominant strategy for achieving operational excellence.

As per the report given by Amuthakkannan (2007) [3], in high precision manufacturing, software based mechatronics systems are widely used to obtained accurate and reliable data. Agoria (2010) [4] studies show that a mechatronics design approach is key to all research avenues and there is likely to be hybrid integrations of two or more approaches in order to drastically improved with respect to their overall performance (adaptability, productivity, quality, reliability and life-cycle costs i.e. reduced energy consumption, reduced waste). Sumathi and Surekha (2007) [5] point of view, manufacturing applications require software to be reliable, high in performance, and low costs.

2. Problem statement

Modern manufacturers are under intense, unrelenting pressure to find new ways to cut costs, improve productivity, and boost customer satisfaction. These parameters might be achieved through developing new innovative ideas. This paper provides a new generic innovative idea and methodology of software based mechatronics system that helps manufacturing organizations to improve their performances considerably and reduce experimental costs, internal costs and lead times for their products significantly. This innovative approach provides virtual machinery for experimentations with simple programs to predict and analyze the relevant data during the decision making processes. The essential parameters required to develop virtual machinery through software based mechatronics systems have been considered as the research problem and solution methodologies are proposed.

3. Literature review

According to Ritchie and Lewis (2003) [6], the wider literature about the role of existing theory, practice and research will shape and lead future innovations. Kothari (2004) [7] expressed that the researcher should undertake extensive literature survey connected with the selected problems. Russell (2006) [8] stated that the contemporary practice of posing research is a wider literature in consistent with more recent articulations of theory methodology and of the closely related case study methodology.

Christopher (2004) [9] outlined that the stages of a product's life include engineering, production and overall testing helps validate appropriate designs, verify appropriate production, and thus reduce wastes. Godfrey (2005) [10] outlined that mechatronics responds to industry's increasing demand for engineers who are able to work across the discipline boundaries. As per the report given by Eiji and Tatsuo (2007) [11], the manual operation process is a waste of time, waste in transportation, waste of movement, overburden etc. for each task. MBT (2009) [12] suggested that making analysis more integral to design; blending of mechanical, electrical, and electronic design is called mechatronics. As per the report given by SPLMS (2010) [13], mechatronics system views and validates electro-mechanical processes for the most efficient production operation possible.

Programmers develop software applications every day in order to increase efficiency and productivity in various situations. Bitter (2007) [14] point of view, the ability of the software to provide abstraction is also significant because it improves code readability. Johnson (1998) [15] stated that the LabVIEW software has advanced the state of software development in graphical programming, user interface design, and development environment. NIC (2003) [16] reported that LabVIEW is a graphical programming language that uses icons instead of lines of text to create applications. As indicated by NIC (2009) [17], LabVIEW is a powerful development environment. NIC (2010) [18] outlined that, with LabVIEW software, it can be quickly create user interfaces that give you interactive control of your software system. Claimed by Pedro and Fernando (2010) [19], LabVIEW is one of the most important software platforms for developing engineering applications and could be connected with different hardware systems.

4. Research approach

The solution given in this paper has been carried out by using the research approach as shown in Figure 1.

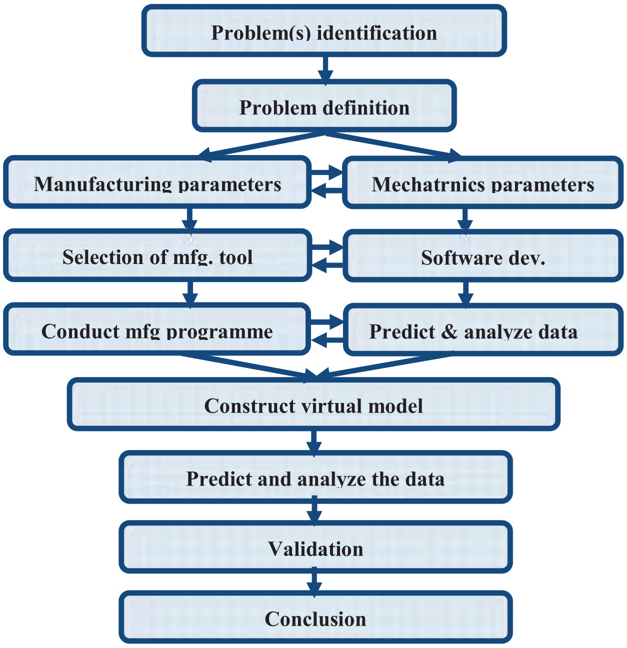

Fig.1. Research Methodology

The problem was identified through lean manufacturing system, likert's scale, rating and ranking method. The state selected problem was defined clearly. The required parameters for the construction of virtual model for the experimentation were studied. The virtual model was constructed using LabVIEW software. The physical product and the virtual experimental model are integrated for the prediction of relevant data. The arrived solutions were validated through traditional method. Finally the model was implemented in the selected environment.

5. Case study

Bill and John (2001) [21] expressed that case study is the both method and tool for research. In order to examine the practical feasibility of development of virtual machinery using software based mechatronics system in a traditional pump manufacturing industry had been chosen.

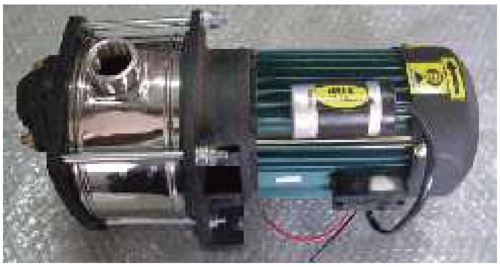

Fig.2. Shallowell jet pump

Based on the field observations, it had been identify that the Shallowel jet model pumps have more problems when compared to other models. During the product selection, Marco (2009) [22] studies were considered. Based on the discussion had with top level management, it had been decided that the Shallowel jet pump (as shown in figure 2) was chosen for the case study.

5.1 Development of virtual machinery using software based mechatronics system

According to Mahalik [23], virtual machinery could perform a repetitive job and continuously monitoring the processes and takes corrective action dramatically to stabilize the processes. The introduction of virtual machinery using software based mechatronics system will achieve these parameters very accurately and precisely. The National Instruments' LabVIEW Software is a graphical development environment which provides advanced functionality and performance that engineer and scientists can use to develop sophisticated applications. LabVIEW is a powerful graphical Language, for signal acquisition, measurement analysis, and data presentation which is highly used for virtual instrumentation. During the software selection, the reports of NIC (2003) [16], NIC (2009) [17] and NIC (2010) [18] were considered. The software development using LabVIEW software is shown in figure 3.

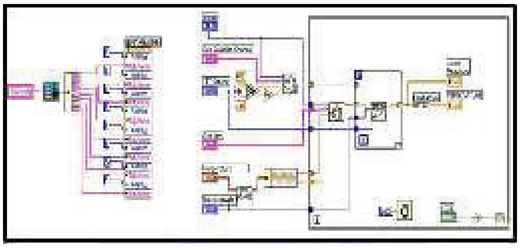

Fig.3. Software development (LabVIEW)

5.2 Apparatus selection

The selection of apparatus for manipulating the input signals and output signals are one of the important phases for experimentation. Anders (2004) [24] stated that a measuring instrument was designed which had an accuracy of a millionth of an inch, increasing the accuracy of the machines dramatically. The required experimentation specifications were met by the design used in NI PCI-6034E (200kS/s) card, included discriminator and logic functions but not fast relative timing or GPS time synchronization. The TOC-92 (3 pins) with one digital connector, 11 bit temperature sensors was chosen for the case study. This temperature sensor is known for its high accuracy, fast response behaviour and also its special long term stability against other semiconductor temperature sensors, they offer an extended measuring range of -50 to 150 °C.

5.3 Experimental Setup

According to Yogesh (2006) [25], Lisa, et al. (2008) [26], Lucienne and Amaresh (2009) [27], experimental setup is a scientific approach to predict and analyze of relevant data for the selected problems. It is oriented to the future in the sense that the researcher is seeking to evaluate something new. The experimental setup for the prediction and analyzes of heat generation is shown in figure 4. The heat generation causes for other problems like rubbing of rotor and stator, bearing failure, winding failure, generate more noises, fatigue of pump rotary parts etc. So, it had been decided that the heat level of the pump has been predicted immediately.

Fig.4. Experimental setup

The software which was already developed using LabVIEW software was opened in computer and kept ready to access the signals from the data acquisition cards as shown in figure 4. The heat generation of every pump was predicted through the LabVIEW front panel. These readings like core temperature, room temperature, input currents, Speed, frequency, suction head, delivery head and discharge were displayed with respect to time.

5.4 Data collection

As stated by Murray (2008) [28] defined knowledge and the ability to turn information and data into effective action, which brings desirable outcomes for a research / organization. This experiment deals with 10 numbers of pumps of the same model namely Shallowell jet pump, TRS1025 model, 1 HP, single phase, self priming. The front panel readings were noted with the predetermined interval of time. The temperature generation was noted every 30 minutes at 160V from the time of starting of experiments are tabulated in table 1. The saturation temperature was taken as the temperature generation of the pump. During the saturation state, the core temperature, room temperature, temperature differences, electric current inputs, speed of the pump, power frequency, suction head readings, delivery head readings, discharges, main wing temperature, auxiliary winding temperature and the cumulative heat generation at the end of each experiment were taken.

Table 1. Temperature raises report at 160V

Sl. No.	**Details**	**Time**					
		2.00 pm	**2.30 pm**	**3.00 pm**	**3.30 pm**	**4.00 pm**	**4.30 pm**
1	Core temperature	31	37	45	46	46	46
2	Room temperature	31	30	30	30	29	29
3	Temperature difference	0	7	15	16	17	17
4	IL (Amps)	5.38	5.35	5.28	5.29	5.22	5.23
5	I/P (Watts)	1340	1335	1325	1322	1318	1318
6	Speed	2464	2454	2445	2438	2420	2408
7	Frequency (Hz)	49.5	49.6	49.6	49.7	49.5	49.7
8	Suction Head (mm. Hg)	210	210	210	210	210	210
9	Delivery Head (Q)	25	25	25	25	25	25
10	Discharge (Q)	45.73	45.8	45.9	45.9	45.92	45.96

Temperature generation details:

R_{MH}	4.09	R_{AH}	8.98	T_E	29	TR_{MW}	82.07	TR_{AW}	**80.08**

Table 2. Temperature raises report at 200V

Sl. No.	Details	Time					
		12.30 pm	1.00 pm	1.30 pm	2.00 pm	2.30 pm	3.00 pm
1	Core temperature	31	39	45	46	46	46
2	Room temperature	31	31	30	30	29	29
3	Temperature difference	0	8	15	16	17	17
4	IL (Amps)	5.08	5.02	4.99	4.96	4.94	4.92
5	I/P (Watts)	1255	1251	1249	1247	1245	1244
6	Speed	2812	2805	2806	2805	2804	2800
7	Frequency (Hz)	49.5	49.5	49.4	49.5	49.4	49.5
8	Suction Head (mm. Hg)	210	210	210	210	210	210
9	Delivery Head (Q)	25	25	25	25	25	25
10	Discharge (Q)	46.66	46.66	46.68	46.70	46.73	46.77

Temperature generation details:

R_{MH}	3.98	R_{AH}	8.89	T_E	30	TR_{MW}	71.76	TR_{AW}	**75.63**

Table 3. Temperature raises report at 240V

Sl. No.	Details	Time					
		9.30 am	10.00 am	10.30 am	11.00 am	11.30 am	12.00 pm
1	Core temperature	29	39	45	45	45	45
2	Room temperature	29	29	30	30	30	30
3	Temperature difference	0	10	15	15	15	15
4	IL (Amps)	4.83	4.78	4.75	4.70	4.8	4.72
5	I/P (Watts)	1169	1162	1159	1153	1160	1151
6	Speed	2841	2837	2832	2827	2828	2811
7	Frequency (Hz)	49.6	49.6	49.5	49.5	49.5	49.5
8	Suction Head (mm. Hg)	210	210	210	210	210	210
9	Delivery Head (Q)	25	25	25	25	25	25
10	Discharge (Q)	51.11	50.97	51.21	50.86	50.92	50.84

Temperature generation details:

R_{MH}	3.89	R_{AH}	8.78	T_E	30	TR_{MW}	64.15	TR_{AW}	**71.42**

Similarly, the power frequency, suction heat, delivery head were kept constant and the supplying voltage was increased from 160 V to 200 V and then from 200 V to 240 V respectively. During the saturation temperature state, the core temperature, room temperature, temperature differences, electric current inputs, speed of the pump, discharges, main wing temperature, auxiliary winding temperature and the cumulative heat generation at the end of each experiment were taken. The prediction and analysis of heat generation at 200 V is tabulated in table 2 and 240 V is tabulated in table 3.. From the observations, it had been noted that the ampere (A) and watts (kW) were reduced and the speed (RPM) and discharge (Q) were increased at 240V when compared to 160 V and 200 V. The heat generation at 240 V also less when compared to other voltages like 160 V and 200 V.

5.5 **Validation**

According to Janeri and Lewis (2003) [29], as a consequence, numerous suggestions are made about how to cross-check the validity of a finding or conclusion (validation) or to allow sufficient access to the research process for others to do so themselves (documentation). The prediction of existing condition of the Shallowel jet pump using software based mechatronics system is validated through a conventional method are tabulated in table 4.

Table 4. Validation (Traditional method)

Sl. No.	Pump No.	Parameters	Voltage		
			160 V	200 V	240 V
1	TRS 1011	Amps (A)	5	5	5
2		Watts (kW)	1320	1250	1160
3		Speed	2400	2750	2810
4		Frequency (Hz)	50	50	50
5		Suction Head (mm. Hg)	210	210	210
6		Delivery Head (Q)	25	25	25
7		Discharge (Q)	45	48	50
Temperature raise (°C)			**80**	**75**	**70**

6. Results and discussions

Mark (2001) [30] pointed out that the discussion aims to describe and explain some different funding options for qualitative research and to highlight the processes and issues involved in each. The development of virtual machinery using software based mechatronics systems very successful for the prediction heat generation. The various outcomes were discussed below.

6.1 Reliability of software based mechatronics system

The reliability of data predicted through software based mechatronics system was validated with a conventional heat analysis system. The data predicted by proposed approach were fully satisfied with the conventional system. The reliability of software based mechatronics system had been validated through conventional system. After the validation, it have been decided that the future data also to be predicted by using software based mechatronics system.

Table 5. Reliability analysis

Sl. No.	Pump No	Parameters	Voltage					
			160 V		200 V		240 V	
			Mecht	Tradl	Mecht	Tradl	Mecht	Tradl
1	TRS 1001 & TRS 1011	Amps (A)	5.23	5	4.92	5	4.72	5
2		Watts (kW)	1318	1320	1244	1250	1151	1160
3		Speed	2408	2400	2745	2750	2811	2810
4		Frequency (Hz)	49.7	50	49.5	50	49.5	50
5		Suction Head (mm Hg)	210	210	210	210	210	210
6		Delivery Head (Q)	25	25	25	25	25	25
7		Discharge (Q)	45.96	45	46.77	48	50.84	50
Temperature raise (°C)			**80.08**	**80**	**75.63**	**75**	**71.42**	**70**

Note: Mecht – Mechatronics system, Tradl – Traditional system

6.2 *Cost and time saving applications*

The cost and lead time of the conventional heat testing and analyzing systems are extremely high in a pump manufacturing industry. The experiment discussed in this research, provides the plug-and-play simplicity for heat generation analysis through the software based mechatronics approach. The comparison between the traditional heat testing system and software based mechatronics approach are shown in table 21.

Table 21. Cost reduction analysis

Sl. No.	Description	Traditional testing (Rs.) *	Mechatronics approach (Rs.) **	Differences (Rs.)	Differences (%)
1	Instrument cost	665,464	284,000	381,301	57.3 %
2	Accessories cost	35,561	58,000	-43,063	- 63.1 %
3	Consumables cost	25,573	15,000	9,697	41.3 %
4	Maintenance cost	75,195	30,000	44,346	60.1 %
5	Material cost	75,876	25,000	50,333	67.1 %
6	Man power	30,462	15,000	15,111	50.8 %

* - The average expenses incurred during a period of three years (Apr 2007 to Mar 2009) in the manufacturing industry were presented.

** - The actual expenses for one year (2009-10) were considered and projected for the next two years periods (2010-11 and 2011-12).

From the above table, the cost of machinery, instruments, consumables, maintenance and man power are reduced significantly. The accessories cost only increased because of the new purchase of data acquisition cards. And the data accuracy and data reliabilities were increased (refer table 17, 18 and 21). These cost reductions have a great impact on product cost reduction which will lead to increase product variety and profitability.

Subsequently, this research has achieved another lead time reduction in the area of testing & validations significantly. This research proposed a methodology to use virtual testing machinery instead of physical testing machinery in order to reduce the testing and validation lead times nearly 59%. The data accuracy was also improved from 2 digits to 4 digits accuracy and the reliability of the data was increased from 90 % to 99% by using virtual machinery approach.

6.3 Benefits in industrial sectors

When the software based mechatronics system is successfully implemented in the pump manufcturing industries, the work-in-process, processing time, testing lead time, and space utilization are improved. The above cited parameters have been demonstrated a considerable improvement in production environment; the manufacturing lead time of each product will be reduced and the organizational performance is improved considerably as shown in figures 5. When the lead time and performances are improved, then the customer satisfaction will improve automatically.

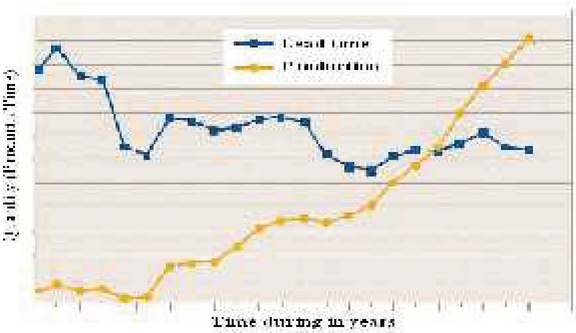

Fig.5. Performance improvements

7. Conclusions

This paper conclusion is based on the experimental analysis during the development and applications of virtual machinery for experimentation using software based mechatronics system. Present manufacturing industry attention illustrates the need for the new innovative approach to develop the manufacturing process and a software simulation for reaching a better solution within short time and low cost. This paper brings in a new innovative approach through the development of virtual machinery using software based mechatronics system to fulfill the manufacturing environments' expectations. This approach had bring the number of benefits like low cost for experimental, prediction of reliable data, lead time reduction, productivity improvements, quick change over, more profitability, more customer satisfaction and innovative technology developments.

Future research of this approach in pump manufacturing industry will include: (1) value chain analysis to be done using RFID, (2) monitoring assembly conditions of parts, (3) monitoring heat generation in pumps, (4) visualizing suction head, delivery head, speed and power consumption, etc., and (5) fine-tune the process of achieving competitive advantages. This will enable the pump manufacturers to observe mathematical relationships among the variables like suction head, delivery head, temperature, power, voltage, etc. Also several software based virtual instrumentation testing stations in the testing laboratories will be developed in-order-to minimize the experimental costs.

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